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Effect of heating application on deformations and pore pressures of a bentonite sand mixture subjected to suction distribution

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ABSTRACT

Generation of electricity in nuclear power plants have produce much energy to society in the world, and remain arising of radioactive waste as results of performance industry with economical growing. Radioactive waste has to be isolated from the human habitat for absolutely so long time period until its radioactivity has decayed to an innocuous situation. This study represents volume strain and axial strain change properties due to exchange temperature and relative humidity such as thermal hydraulic crucial factors. Suction control is based on vapor pressure technique, and incorporate with heat. This testing program consists of four test programs that one is measurement of pore fluid pressures in bentonite-sand mixture using high temperature resistance pressure sensors. Unsaturated bentonite sand mixture with various of dry densities are prepared at specified water content constant. As results of obtained between pore pressure and temperature in developed steel mold using high quality pressure sensor. Then, another one is of measurement deformation both whole volume and axial strain for unsaturated specimens. The deformations induced by changing relative humidity and heat that measured using a developed steel mold in order to make resistance to high temperature. Previously the relationship between temperature and relative humidity is prepared in order to convert into suction values, and contribute to estimate suction value. In addition, unconfined compression test is conducted out to determine unconfined compressive strength for specimens subjected to thermal effort.

Keywords: Bentonite, Heat, Deformation, Strength, Pore pressure

1 INTRODUCTION

Generation of electricity in nuclear power plants have produced much energy to society in the world, and have remained arising of radioactive waste as results of performance industry with economical growing. Radioactive wastes have to be isolated from the human habitat for absolutely so long time period until its radioactivity has decayed to an innocuous situation. This study has some proposing concepts associated to couple phenomena related to Thermal-Hydraulic-Mechanical properties (Huertas et al. (1997), Lloret et al. (2004) and Sellin et al. (2020)) for bentonite-sand mixture, which is one of important components in high level radioactive waste disposal constructed under deep underground with hard rock. Variations in both dry density and temperature due to heat for compacted, unsaturated bentonite-sand mixture as one component of radioactive waste disposal barrier tend to the most important categories for engineering. Thermal effort to bentonite-sand mixture properties is widely known as one of crucial trigger factor in couple phenomena. Many published domain and experimental reports have mentioned in previous studies that the appeared properties are swelling pressure and swelling deformations with several dry densities. However, in some reports, it seems to be the absence of experimental data sets in the determination of deformations with progressive of heating associated to measurement of pore pressure.

2 PURPOSE OF THIS STUDY

This study helps to establish the connection between the basic deformation properties and producing the pore pressure under heat conditions for bentonite-sand mixture. This paper represents accurate determinations of shrinkage/expansion behaviour and considering occurrence of pore pressure in void structure for variation in temperatures. Also, developed apparatus is able to control suction equilibrium through volume change and axial direction deformation for specimens, and using vapor pressure technique is incorporation to contribute to hydration phenomena for bentonite-sand mixture specimen

(A) Measurement of volume change and unconfined compressive strength
Free deformation
20, 40, 60 and 80 degrees
RH 93 %, 75 % and 33 %
Dry density 1.600 Mg/m^3
Water content of 17.0 %
RH: Relative humidity

(B) Measurement of axial strain and unconfined compressive strength
No allow lateral deformation in expansion
20, 60, 80 and 100 degrees
No control relative humidity
Three different dry densities
Water content of 17.0 %

(C) Measurement of pore pressure
80 degrees constant
Five different dry densities
Water content of 17.0 %
Undrained - unexhausted condition

Figure 1. *Testing programs*

Figure 2. *Specimens and salt solutions*

prior to subjection heat. This testing program consists of three test programs that one is measurement of pore fluid pressures in bentonite-sand mixture using high temperature resistance pressure sensors. Taking a between pressure and temperature in developed steel chamber using high quality pressure sensor as a calibration. Then, another one is of measurement deformation both whole volume and axial strain. The deformation induced by changing relative humidity and heat efforts that a developed steel mold use in order to remain a resistance to high temperature. Previously the relationship between temperature and relative humidity is visualized in order to convert into suction values. Subsequently, unconfined compression test is conducted out to determine unconfined compressive strength for bentonite-sand mixture subjected to heating, which is effectively strength parameter regard to predict safety estimation for artificial barrier system constructed around deep hard rock.

3 SOIL MATERIAL AND TEST PROCEDURE IN THIS STUDY

3.1 Soil material

In previous studies, two different bentonites are used, and are sodium bentonite and calcium bentonite in the world. Each bentonite is selected corresponding to majority research subjections. This testing program have the purpose such as deformation, strength and pore fluid pressure under heat produce for unsaturated condition. Considering, Kunigel V1, a sodium bentonite, is used in a series of three testing programs to confirm the Thermal-Hydro-Mechanical properties in experimental laboratory studies. Owing to its high montmorillonite content, the bentonite has a fine content greater than 95.0 %. In this testing program all of specimens mixed a silica sand, named Iitoyo No.4, into the sodium bentonite, which has a uniformity grain size distribution. The air-dried bentonite and silica sand were humidified by spraying deionized water to reach the desired water content, which was 17.0 % common in this test.

3.2 Specimen

All specimens had a diameter of 38 mm and a height of 76 mm for all of series of testing programs that are statically compacted using a hydraulic oil jack, which has a capacity of 70 MPa. The bentonite sand mixture is put into the stiffness steel mold with an inner diameter of 38.0 mm, a thickness of 18.0 mm and a height of 76.0 mm. In term of friction stress at inner surface and soil material, it is assumed to be neglection, because of density distribution is equal in previous experimental works. Then, the pre-consolidation pressure is measured at processing the compaction, as result, approximately 10 MPa is estimated. The initial specimens have the following physical properties: a dry density of 1.600 Mg/m^3, a void ratio of 0.710, and a degree of saturation of 65.6 %. The prepared specimen size was relatively small, and the ratio height of diameter is just 2.0 that is certainly for investigation of mechanical properties such as shear strength due to unconfined compression test.

Figure 3. *Steel mold used in Testing program (B)*

Figure 4. *Steel mold installed pressure sensors*

Figure 5. *Porous stone installed at mold*

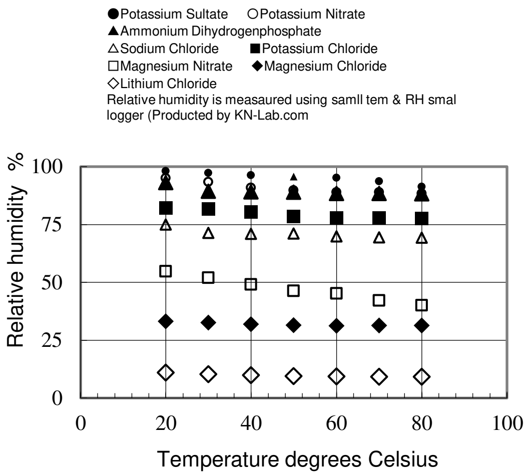

Figure 6. *Changing of relative humidity with temperature*

3.3 Apparatus and equipment used in this study

This testing programs consist of three testing programs, and key futures are incorporated in Fig. 1. These test programs are divided categories into thermal-hydration and thermal-mechanics. Testing program (A) prepares the steel chamber with a diameter of 10.0 cm and a height of 12.5 cm as shown in Fig. 2. Salt solutions are used in order to control suctions (i.e. relative humility). Testing program (B) is given the different steel mold with Testing program (A) as shown in Fig. 3, and a thickness of 16.0 mm, an inner diameter of 38.0 mm and a height of 76.0 mm, the diameter is same with all specimens. The specimens not allow the lateral expansion deformations due to isotopic heating conductivity. Unconfined compression test used a thermal triaxial compression test apparatus for common two programs in Testing programs (A) and (B). In case of Testing program (C), the steel mold is used as shown in Figs. 4 and 5, which installed two pressure sensors (PHF-S-3MPS3B manufactured by KYOWA) with high temperature resistance.

3.4 Testing program (A) in series of this testing program

This study conducted out some experimental tests in order to investigate Thermal-Hydraulic-Mechanical phenomena such as coupling behaviour that three testing programs are incorporate. Each testing program is explained as following: In case of Testing program (A), all specimens are installed in the steel chamber with specialized salt solution as shown in Fig. 2, and the specimen is applied the heat under close condition (i.e. the chamber complete sealed). Controlled temperatures are from 20 degrees

Celsius to 80 degrees Celsius. Also, the given salt solutions established relative humidity, and are range from 93.1 % to 33.0 % at twenty degrees Celsius. The salt solutions are Magnesium Chloride,

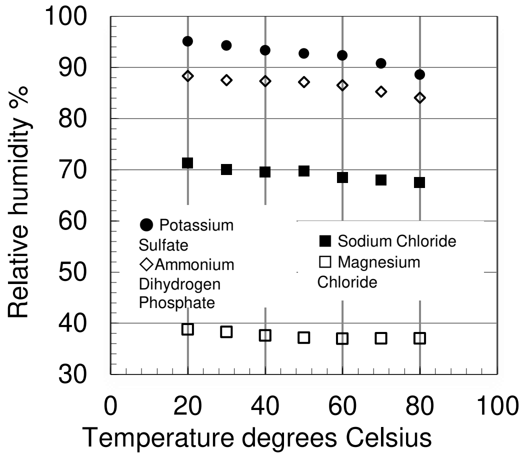

Figure 7. *Relative humidity with temperature*

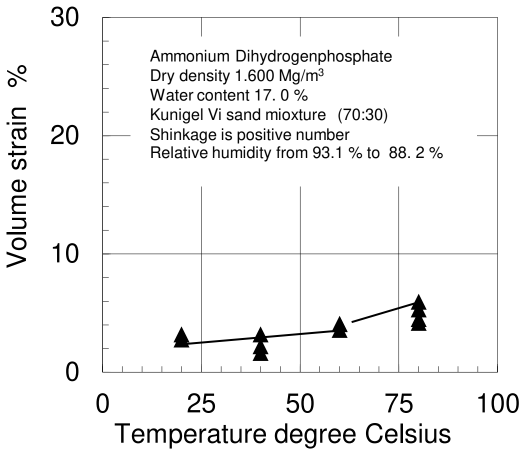

Figure 8. *Volume change (RH 93.1 %)*

Sodium Chloride and Ammonium Dihydrogen Phosphate that are able to create 33.0 %, 75.0 % and 93.1 % in respectively. After equilibrium to temperature and relative humidity, volume changes for all of specimen are directly measured. As above mentioned, it is vapor pressure technique.

The steel mold is prepared that some salt solutions are installed in order to investigate relative humidity changing in Testing program (A). Whole the mold was placed in thermostat oven, in which controlled a range from 20 degrees Celsius to 80 degrees Celsius. Variations of salt solutions are used to verify relative humidity ranges, and the results is described as shown in Fig. 6. Determined relative humidity has a range from 95 % to 9.0 %. All of chemical substances have common tendency which is reduction with increment of temperature regardless of relative humidity at 20 degrees Celsius. Much reductions of relative humidity are indicated in such tendency when Magnesium Nitrate is place in the mold, that it is from 54.7 % to 40.2 % in relative humidity. In other words, attempting of measurement of relative humidity associate the equipped air circulation system, and it is obviously provided that measured relative humidity decrease with increment of temperature as shown in Fig. 7. All of salt solutions have similar with the results as shown Fig. 6. Relationship between temperatures and relative humidity as calibration specification is considerable useful to predict or estimate applicable relative humidity on heating process. After equivalent to given each relative humidity, unconfined compression test is conducted out using a thermal triaxial compression apparatus, and compression speed is confirmed as a 1.0 % per min.

3.5 Testing program (B) in series of this testing program

Three different dry densities are adopted for Test program (B), which apply the heat efforts with a range from 20 degrees Celsius to 100 degree Celsius. Dry densities are 1.600 Mg/m^3, 1.400 Mg/m^3 and 1.200 Mg/m^3 with a water content of 17.0 % constant. The steel mold has a specimen, and sealed with upper portion plate and bottom plate. Whole the steel mold is placed into the thermostat camber, and the temperatures are controlled to 20 degrees Celsius, 60 degrees Celsius, 80 degrees Celsius and 100 degrees Celsius. A testing period of one month is required for Test program (B), it is predicting that changing of pore fluid pressure is induced by heating process, is not able to measure in this testing. Beyond end of heat, deformation of axial direction for each specimen is directly measured using a conventional calliper. All specimens not allow the expansion deformation in the diameter way. Also, the lateral surface, upper and bottom surface of all specimens are observed to complex cracks occurrence, and closely the changing of shear resistance in the void structure. As next process, unconfined compression test is conducted out under remaining each regulated temperature, and the thermal heating triaxial compression apparatus are used for determine the unconfined compressive strength. Selected compression speed is 1.0 % per min that is common in the soil mechanics experimental standard test.

3.6 Testing program (C) in series of this testing program

Thermal performance is significant key factor to relevance the phenomena of bentonite sand mixture, and it is possible to create the pore fluid pressure. The produced pore fluid pressures effort on the mechanical properties for bentonite sand mixture. To measure the pore fluid pressures, an improved steel mold is used in Testing program (B), as shown in Figs. 4 and 5, with two pore pressure sensors

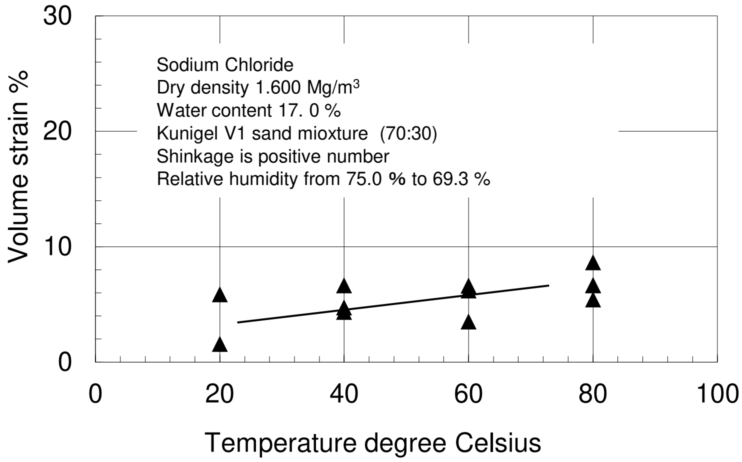

Figure 9. *Volume change (RH 75.0 %)*

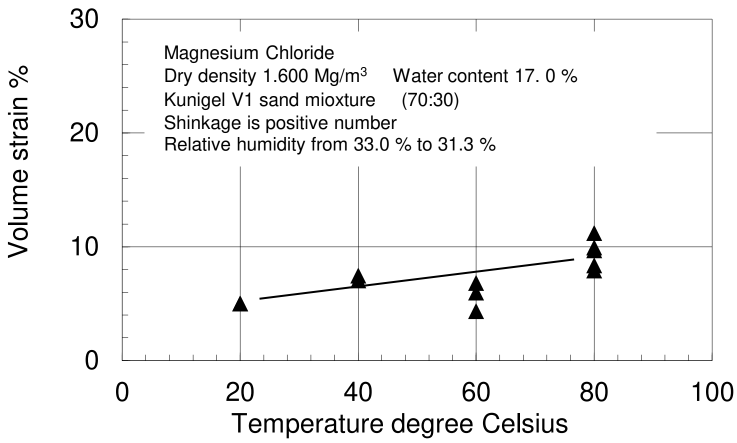

Figure 10. *Volume change (RH 33.0 %)*

installed on the upper and lower portions of the lateral surface area and the distance is 18.0 mm. Two pore pressure sensors named as PHF-S-3MPS3B manufactured by KYOWA. As specification, capacity is 3.0 MPa, temperature resistance is minus 40 degrees Celsius to plus 160 degrees Celsius. Figure 5 shows the porous stone (i.e. orange colour plate in the hole), is placed between specimen and the tip of pressure sensor which has a thickness of 2.5 mm and classification is typical coarse group with high permeability. It is need to make a sealing for the leakage pore fluid due to heat. Considering a rang is from 0.800 Mg/m^3 to 1.600 Mg/m^3 in dry density to elucidate the influence of presentation for pore fluid pressure with the difference of dry density. Iso-tropic heat action is supplied indirectly to the specimen through the mold. Preparing some specimens with various dry densities is play a certainly role in the occurring of unsaturated bentonite sand mixture properties functions regard in thermal-hydraulic phenomena.

4 TEST RESULTS OBTAINED FROM THIS TESTING PROGRAMS

4.1 Volume strain induced by heat and different relative humidity

This study focused on volume change under allow free deformations due to heat and various of relative humidity for unsaturated bentonite-sand mixture that deformation probably cause the reduction of stiffness and strength. The occurrence of deformations is close realized to some property's functions in Thermal-Hydration-Chemical properties. Therefore, two factors considered to represent the deformation, and they are heating actions and exchange relative humidity. It is easy to controlled the relative humidity due to use salt solutions on vapor pressure technique concept. The vapor pressure technique prompte total suction, and it sum of these two suctions; namely, matric suction and osmotic suction. Osmotic suction almost occupies in the vapor pressure exchange, and the osmotic suction is a function of the

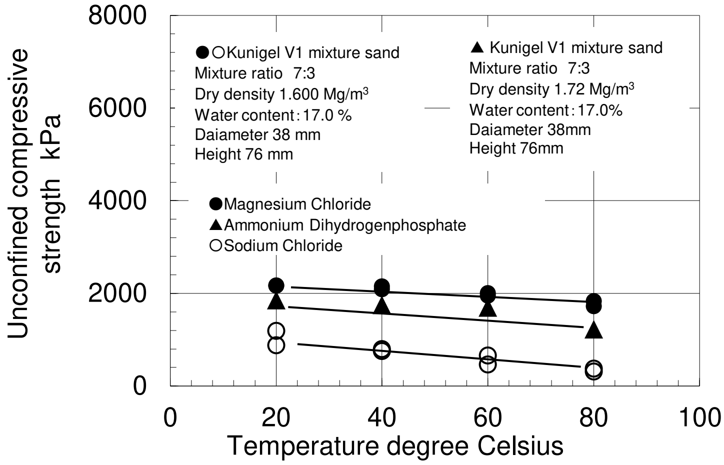

Figure 11. *Reduction of unconfined compressive strength with temperature*

amount of dissolved salts in the soil moisture. Ammonium Dihydrogen Phosphate, Sodium Chloride and Magnesium Chloride as salt solution contribute to control relative humidity at wide ranges from 93.0 % to 31.0 %. Volume strain was estimated to measure diameter and height for specimen, and the obtained volume strain is described with temperature, which had a range from 20 degrees Celsius to 80 degrees Celsius as shown in Figs. from 8 to 10. Verified volume strain indicated shrinkage behaviour and maximum shrinkage was difference with temperature and relative humidity. When small relative humidity and high temperature (i.e. 80 degree Celsius), unsaturated bentonite-sand mixture specimen describe high shrinkage strain. Also, producing the shrinkage was closely to temperature, and the tendency seems to be liner relations.

4.2 Unconfined compressive strength for bentonite sand mixture having volume changes

All specimens, are equivalent to given temperature s and relative humidity as above mentioned in Section 4.1 that used for determination of unconfined compressive strength according to unconfined compression test. While compression process in the triaxial compression cell, reproduce the temperature at 20, 40, 60, 80 degrees Celsius remaining. As mechanical component, removing of unconfined compressive strength for unsaturated bentonite subjected to heating and developed relative humidity is significant factor. The specimens except of 20 and 40 degrees Celsius have some cracks, and varieties of unconfined compressive strength are indicated as shown in Fig. 11. All specimens derive that the unconfined compressive strength decrease according to heat, are smooth tendency in plotted strength with temperatures. Particularly, the specimens with equivalent to relative humidity of 75 % that describe the further reduction by heat, and the different in strength is over 500 kPa between 20 degrees Celsius and 80 degrees Celsius.

4.3 Axial strain induced by heat under no allow lateral expansion

As other method regard to investigation of bentonite sand mixture subjected to heat, the Testing program (B) is suggested that no allow of lateral deformation in expansion condition is absolutely different. Heat controlling to bentonite sand mixture derive significant some problems and damages associated to mechanical properties such as occurrence of cracks, reduction of yield stress, changing of rigid modulus, irreversible deformations, further reduction of soil moisture and decreasing of shear resistance. Actually, the results induced by heating actions verify various tendencies. This study conducted out heat up in unsaturated bentonite-sand mixture specimens with three difference dry densities (i.e. a range from 1.200 Mg/m^3 to 1.600 Mg/m^3), while temperature range is from 20 degrees Celsius to 100 degrees Celsius at each temperature step. All specimens are only possible to produce expansive deformations toward axial direction. This study, no attaching, no predicting the magnitude of friction at the specimen and inside lateral surface steel mold wall, is negligible. Three different dry densities are selected that are 1.200 Mg/m^3, 1.400 Mg/m^3 and .600 Mg/m^3, and all of these specimens are common the water content of 17.0 % and bentonite-sand ratio is 7:3. All specimens present the shrinkage phenomena at beginning of test air surrounding of 20 degrees Celsius. All specimens present the shrinkage phenomena at 20 degrees Celsius. Contrasty, exchange axial strain with increment temperature that

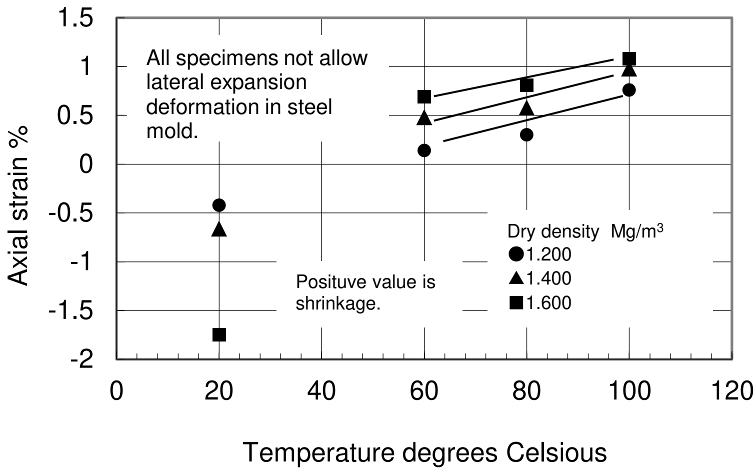

Figure 12. *Producing of shrinkage with heat*

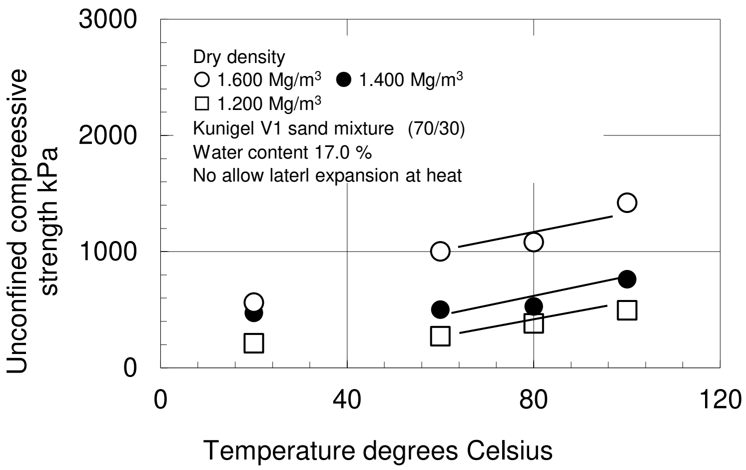

Figure 13. *Increment of unconfined compressive strength with temperature*

are coincident regardless of different of dry density, axial strain stays in remaining expansion deformation as shown in Fig. 12. Beyond temperature of 60 degrees Celsius, all data sets are possible to elucidate establishing each straight line, each slope are the accurate similar.

4.4 Unconfined compressive strength up to 100 degrees Celsius

All specimens moderated in Section 4.3 focuses on the shear resistance in order to interpret thermal-mechanical properties functions, the relationship between temperature and unconfined compressive strength is produced as shown in Fig. 13. Investigation of the unconfined compressive strength used the thermal triaxial compression apparatus. It obviously confirms that each strength some to increase with the dry density regardless of the temperature. The influence of dry density on strength is difference that the cause is temperature alternations. The difference in strength varied from 350.6 kPa to 917.1 kPa, when temperature are 20 and 100 degrees Celsius, because of, strength in dry density of 1.600 Mg/m^3 grow further at 80 degree Celsius. For both two dry densities (i.e. 1.200 Mg/m^3 and 1.400 Mg/m^3) the strength increases smoothly with heat, and verified lines are seem to be straight with some slopes. These slopes are closely at range from 60 degrees Celsius and 100 degrees Celsius. Case of dry density of 1.600 Mg/m^3 compare, the large slope is provided that are 10.5 kPa per degree Celsius. Other two lines have a slope of 6.5 and 5.5 kPa per degree Celsius.

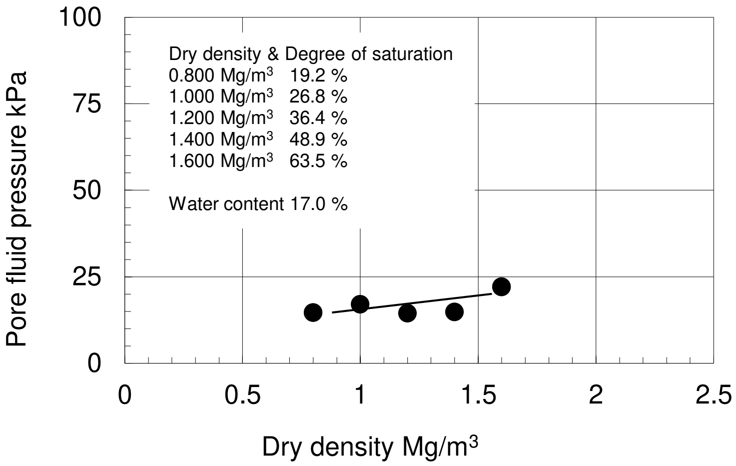

Figure 14. *Measurement of pore fluid pressure with various of dry densities*

4.5 Investigation of pore fluid pressure measured at lateral surface

Predicting the change of fluid pore pressure due to heat, this test conducts out to measure the exchange of pressure using a developed steel mold, are installed two pressure sensors at lateral surface. Various dry densities are given to the specimens that increase from 0.800 Mg/m^3 each dry density of 0.2 Mg/m^3 dry density step up to 1.600 Mg/m^3. The pore pressures are measured two places at lateral surface, are distance of 18.0 mm from upper and bottom portion. Heating performance that induce the increment of pore pressure, and it is not clear in previous experimental works regard to radioactive waste disposal system. Establishing the pressure properties as one of thermal couple phenomena is extremely important matter for geo- environmental practices. All measured data sets under 80 degree Celsius take an average, and plotted with dry density as shown in Fig. 14. Occurrence of pore fluid pressures is confirmed, and is independent on dry density. Other hands, possible to assume that increment of dry density induce increment of pressure due to heat at water content constant.

5 CONCLUSIONS

The obtained results are summarized as following; The subjections that exchange of relative humidity and heating are induced significant volume change under allow free deformation. Shrinkage volume strain increase according to increase temperature. Also, measured unconfined compressive strength verify reduction with increment of temperature. Case of no allow to lateral expansion deformation are attempted for unsaturated bentonite sand mixture accomplished three dry densities, measured axial strain under a range from 20 degree Celsius to 100 degrees Celsius. Beyond 60 degrees Celsius axial strain provide with temperature using a straight line for each dry density. Heat induce that unconfined compressive strength increase smoothly with temperature, and it is different to the obtained results above mentioned. It is prediction that the two different tendencies cause in given deformation condition such as allow and not allow in lateral deformation. Occurrence of pore fluid pressures are verified under

80 degrees Celsius for unsaturated bentonite sand mixture, and have various dry density and degree of saturations. The tendency present straight line with dry density.

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